Missile Seekers for Strike Warfare Beyond the Year 2000

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Abstract

The goal of this paper is to explore emerging post Cold War missile seeker requirements that will lead to new seeker procurements in the year 2000+. These requirements are compared to existing missile seeker products to show where technology deficiencies exist. A projection is made of what seekers will be deployed in the near future to fill important military missile user needs and where technology investments will be made to develop fully capable missile seekers. The orientation of the presentation is on missile seekers as a product and the functionality they provide the military user community. Therefore, the presentation discusses new functionality not included in seekers built in the 1900's because of technology limitations or lack of sufficient user requirements.

Introduction

The 1900's has brought the development of precision munitions and established a base for major improvements in missile seekers during the next millenium. This paper addresses what new missile seekers will enter military inventory during the first part of the new millenium based on developing post cold war requirements for missile seekers. This paper will focus on what the author believes are a few key requirements that will drive missile seeker developments and technology investments. Missile seekers will be viewed more from a product and customer need prospective rather than a technology perspective.

Flying Into The New Millenium

At the end of this millenium, technology appears to be king and advances appear to move at a very rapid pace. Commercial technology truly appears to be flying into the next millenium. Major advances in military technology are equally impressive although held back some by a post cold war restructuring of the military/industrial complex. This restructuring raises questions not only about what the mission of the military will be in the early part of the new millenium and what equipment fills that need but how industry makes a profit and stays solvent in a shrinking market. Figure 1 illustrates this pivotal time in military history and the need to adjust rapidly to a world going through major military and geopolitical changes. In spite of the many uncertainties, there are new requirements emerging for a new generation of more capable missile seekers which industry will have to fill in a more economical fashion than in the past. Because commercial technology appears to be moving at a faster pace than military technology, filling these needs more economically may require finding a way to exploit commercial products without major compromises in military preparedness.

Seeker Functions

The reason a seeker is put in a missile is because there is uncertainty in the missile launch point, flight path or target location that makes it impossible to achieve the desired accuracy without a seeker. For some targets and bomb sizes, GPS accuracy is sufficient and a seeker is not required to satisfy mission objectives. Seekers can also provide autonomy allowing the launch aircraft to move out of the range of air defenses or move to the

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next target more rapidly. It is helpful to keep this functionality in mind when reviewing requirements and the needs for new seekers.

A new developing seeker function is real time, bomb impact reporting that helps determine the need for a second weapon on target. Since an increasing number of seekers are imaging seekers, the potential exists to transmit the pictures back to the launch aircraft or support aircraft just prior to weapon impact. This doesn't verify warhead detonation but verifies correct aimpoint selection. Depending on the reliability of the fuse and warhead, bomb detonation can be assumed to have occurred.

Changing Seeker Requirements

In the opinion of the author seeker requirements have and will change dramatically during the next millenium in many mission areas as illustrated in Figure 2. Seekers built during the 1900s were designed for major world wars rather than small wars with a high likelihood of friendly forces intermixed with enemy forces or weapons of mass destruction hidden in civilian areas.

New seeker requirements include antistealth, hit-to-kill at an affordable price, and in the area of strike warfare both the Desert Storm and Kosovo operations demonstrated the need to attack through the clouds and engage targets autonomously. Filling these newer and in some cases older requirements with technology that may finally have reached the required level of maturity will be a high priority task of military planners.

Impact of GPS on Missile Seekers

The introduction of GPS has had an impact on missile seeker developments and is worthy of some discussion but the impact is not what some military planners hoped it would be. Some military planners hoped that GPS would reduce seeker requirements, and therefore, reduce the procurement cost of seekers. To some extent they have reduced fixed target search requirements but this hasn't had a major impact on seeker costs. GPS has had a major impact on dumb bombs by providing a way of reducing their dispersion through the introduction of INS/GPS tailkits and perhaps the final days of dumb bombs will come to pass.

Figure 3 illustrates what the author sees as the real impact of GPS on seekers for mission areas such as strike warfare. First the introduction of an INS/GPS has meant that the INS becomes the source of high rate autopilot commands instead of the seeker providing high bandwidth line-of-sight rate information. The seeker becomes a low rate navigation update device to the INS. This gives imaging systems and ATR systems more time to perform their processing, relaxing throughput requirements on the ATR. Fixed target ATR is clearly reduced since the ATR knows the precise approach range and angles.

A final point about GPS is its use in the military strategic and tactical mission areas plus commercial applications. The use of GPS to guide weapons means any attempt to negate the effectiveness of GPS is a threat to all three of these communities and perhaps the commercial application is the one of greatest value to the voting public. Attempts to destroy GPS satellites could also raise a conflict to the level of nuclear warfare.

Future Investments, Technology Thrusts and New Products

Future investments leading to new technologies and products will be driven as always by those needs the military decides have the highest priority modified some by political considerations as illustrated in Figure 4. Figure 4 lists some needs the author believes military planners have or will decide are a high priority such as cloud penetration or high impact angle in the area of strike warfare. In the current technology base are E/O and radar seekers of various forms and in the research base are some new types such as imaging passive MMW plus multisensor. Cloud penetration will create a need for a radar seeker of some form. In the authors opinion, this is most likely a synthetic aperture radar seeker and this will drive industry to invest in affordable SAR designs through lean manufacturing, certified suppliers and use of commercial products. These initial radar designs will have to develop solutions for the high impact angle requirement since radars have difficulties when transmitting straight into the ground.

As figure 5 illustrates, there is a need for each type of seeker depending on the mission area. Each of these developments compete for the same pool of production dollars.

National Missile Defense (NMD) my have the higher nation priority but it is limited by treaty restrictions. NMD may receive most of the technology investment forcing industry to pickup some of the technology investments required to move new strike warfare seekers into the military inventory. Antistealth by the nature of the difficulty of the problem may remain an unfilled need or approached from directions other than new seekers. Antistealth will be an area for continuous research investments.

Cloud Penetration Problem

Performing the trade studies to select a seeker for a mission where the target area is covered by clouds involves several factors as illustrated by Figures 6. Obviously the sensors ability to see through the clouds is a key factor. As shown at the top of Figure 6, radar seekers have a clear advantage over E/O seekers that are cloud blind. If all targets can be approached at shallow angles such as bridges and industrial buildings, a radar seeker would be a clear winner. Some targets need to be attacked from high approach angles and radars have difficulties once the approach angle gets close to vertical. Near vertical, radar functions more like an altimeter than a traditional radar seeker and range resolution doesn't separate targets from ground clutter. E/O seekers function equally well at high and low depression angles but don't see through the clouds. For these different reasons, both types of seekers are forced to either pop under the clouds and pop up to increase impact angle or just blast through the clouds at a high impact angle. Both approaches have their problems. The SAR can pick an aimpoint at long range and fly inertial to the high impact angle but this stresses the INS to hold the accurate long range fix and drives up the cost of the INS system.

Future Radar Seeker Developments

Many military planners hoped that radar seekers for strike warfare could be fielded in the 1900s and several good attempts were made to achieve this goal such as the MMW Maverick program. For many reasons, this goal must be met in the new millenium. There are three basic technologies that could fill this need and they are called out in Figure 7 as Active & Passive MMW or SAR. Passive MMW using arrays of detectors is still in the early stages of development but progressing quickly. Until a mature producible camera including auto calibration enters the market place it is unlikely that any Passive MMW seeker prototypes will be built. MMW has lost the resolution advantage of being at very high frequencies to SAR seekers that rely on the more affordable approach of high speed computer processing. MMW seekers will need longer detection range which means more transmitter power and more sensitive receivers plus new signal processing techniques to enhance resolution so it can complete against SAR for a Strike Warfare mission. MMW does retain the advantage that it can see the target at nose on aspects unlike SAR that must look to the side and fly a spiral trajectory and go blind at much longer ranges. If SAR seekers fail to prove that squint mode guidance can achieve high performance, active MMW may appear once again as the leading seeker contender. All active radar seekers must develop processing techniques compatible with high angle attack.

Future of Infrared Seekers

Infrared seekers such as the JASSM seeker, will continue to be important in many Strike Warfare mission areas such as engaging relocatable targets which may often be targets of opportunity because of their minimum exposure time. Figure 8 shows trends in infrared seekers. In the next millenium uncooled infrared seekers will be fielded at a lower cost and with a longer shelf life that cooled seekers. Initially these seekers will fill a need for low performance/low cost seekers but their performance capabilities will grow and they will work their way into mission areas requiring high performance. Cooled detectors will have to offer more than low noise and high resolution. Cooled detector arrays will push for higher yields and greater uniformity to compete with uncooled detectors. Even more important cooled detector arrays are in a better position to offer multiple wavebands and on chip processing. Scene based calibration techniques will also slowly become a standard eliminating the need for expensive infrared calibration reference. The growing competition between uncooled and cooled arrays will accelerate forward improvements in both product areas.

Missile Level Trades

In general seekers are looked at as receiving requirements that are flowed down from the missile level, but when cost is an independent variable, it may be appropriate to trade seeker performance for airframe performance as illustrated in Figure 9. Returning to the cloud penetration problem the minimum cloud ceiling that can be handled depends both on the seeker acquisition range and the maneuver capability of the airframe. The higher the airframe maneuverability, the longer the seeker can wait to acquire the target. In the case of moving targets, this directly effects the ability of the missile to stretch in order to catch a target that has moved away from the initial acquisition point. The next millenium may very well see a push for higher performance airframes as a way to reduce seeker requirements, stretch E/O seekers into the cloud penetration scenario or drop the minimum cloud ceiling which increases total number of operational days. Figure 10 shows the amount of airframe maneuverability required as a function of sensor acquisition range and target uncertainty. As sensor acquisition range shrinks because of decreasing cloud cover, the required missile maneuverability increases rapidly. Since the equation is basically $.5at^2$ where a is maneuverability and t is time of flight, maneuverability increases inversely with the square of acquisition range (time of flight is acquisition range divided by missile speed).

Synthetic Aperture Radar Attractive Adverse Weather Seeker

As already stated and shown in Figure 11, SAR is a leading contender for an adverse weather seeker for Strike Warfare. Its ability to provide a high resolution image in all weather at long ranges coupled by computers being the enabling technology make it hard to beat. Millimeter wave seekers that exploit shorter wavelength to achieve better resolution cannot achieve SAR resolution even at moderate ranges. The unanswered questions about SAR is the accuracy that can be achieved using squint mode guidance (missile spirals into the target) and the realizable average unit production prices that can be achieved using the current supplier base for radar components. There is also a question of whether current tactical grade IMUs required to compensate the SAR phase for missile motion are adequate to meet ATR image quality requirements. Once these questions are satisfactorily answered, a SAR production go ahead may be in the near future.

Figure 12 illustrates the subsystems that make up a SAR seeker. In many ways they don't differ from any radar seeker. One of the things that does differ is the quality of the components that are used in the subsystems. The waveform generator needs to be very linear with low phase noise. Fortunately modern missiles have inertial navigation systems which no longer get counted against the cost of the SAR which must have an INS for motion compensation. The biggest difference between a SAR and a MMW radar is the SAR processor since it must handle the complicated image format process and perform complex functions such as a 2-D fast Fourier transform. With modern computers, this is not only very possible in a small, affordable subassembly but it is likely to decrease in price over the life of the SAR seeker production life.

The emerging new Hit-to-Kill technology in the air defense arena, as illustrated in Figure 13, may also find its way to Strike Warfare for similar reasons that make it attractive to the air defense community. Hit to kill means reducing the seeker line of sight measurement error to sufficiently small numbers that the missile hits a lethal aimpoint on the target.

Combining air defense hit to kill technology with ATR may fill an important gap in Strike Warfare reducing collateral damage associated with destroying some weapons of mass destruction, and potentially reducing weapon cost. This will become increasingly possible as the air defense community reduces the price of ownership by maturing the technology, developing a mature supplier base and validating production processes.

Stealth

Stealth has received so much publicity that it must be considered for two reasons. Strike warfare needs to be aware of what steps the enemy may take to defeat stealth and ground force may develop their own stealth techniques to protect themselves from precision bombing. Some factories have already gone underground becoming stealthy. Relocatable targets hide in holes in the ground for stealth. As Figure 14 states, stealth is

associated with the radar range equation. Reduce the radar cross section of the target and the seeker receives less return power. Defeating stealth requires changing another parameter of the radar equation to counter the lower radar cross section. The simplest approach is more transmitted power using high power transmitters. The radar receivers can be made more sensitive or the antennas can be designed for higher gain. The changes that will occur in the future will probably be a mix of these approaches. Strike warfare may be pushed to higher altitudes and may have to attack more concealed targets creating new seeker antistealth requirements.

Future Strike Warfare Seekers

The new seekers that will be deployed for strike warfare will be synthetic aperture radar seekers since they are a good match to ATR and are a good fit to INS/GPS midcourse guidance. Initially these seekers will be deployed for fixed targets. As new systems capable of attacking relocatable targets go into production, an infrared sensor will be added to the SAR to track the target all the way to impact. The SAR seeker can track the target through the cloud cover and hand off to the infrared seeker in the terminal flight phase. The infrared seeker will be an uncooled seeker that can perform satisfactorily at short ranges.

In addition to SAR seekers, low cost infrared seekers using uncooled sensors or low cost cooled arrays will be developed for lower cost weapons such as JDAM, JSOW or a Paveway like weapons. These seekers will strive for lowest cost to achieve better than GPS accuracy for increased target kill capability.

Other enhancements to strike warfare seekers will be transmitting the seeker imagery back to an aircraft for target impact assessment and potentially the extraction of intelligence information. As technology develops, the goal for weapon CEP will move towards hit-to-kill type accuracy to reduce collateral damage and destroy hidden targets that might have only small pieces exposed to attack aircraft.

Summary and Conclusions

In summary, the next millenium will be the age of the intelligent missile seekers that will achieve all weather performance and near total autonomy. The weapons will begin to match the capability of modern aircraft and the needs of the warfighter. The percentage of weapons on target will steadily grow and weapon accuracy will continually improve towards hit-to-kill. In order to protect their warfighting capability, nations will conceal and mask more of their weapon factories, aircraft shelters, and munitions storage bunkers, creating a stealthy type of environment. This need will be fed by an increase in sophisticated reconnaissance assets making it difficult to hide from strike aircraft. Soon strike warfare will have to respond to a growing ground target stealth problem with more sophisticated sensors and new weapon delivery tactics.

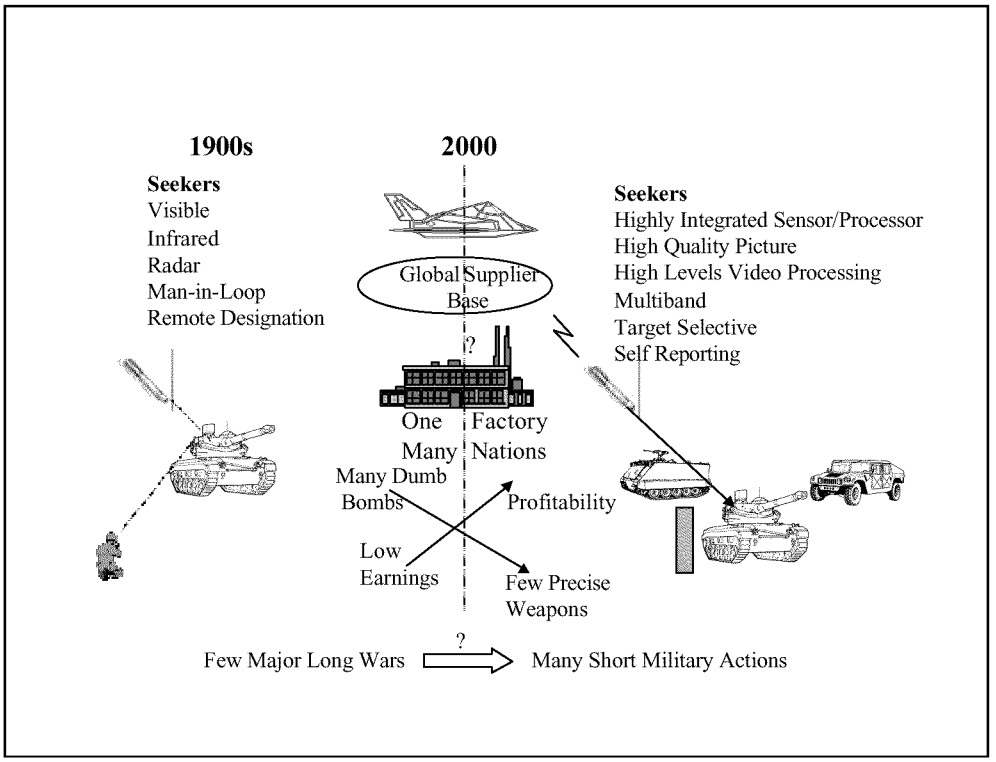


Figure 1. Flying Into The New Millenium

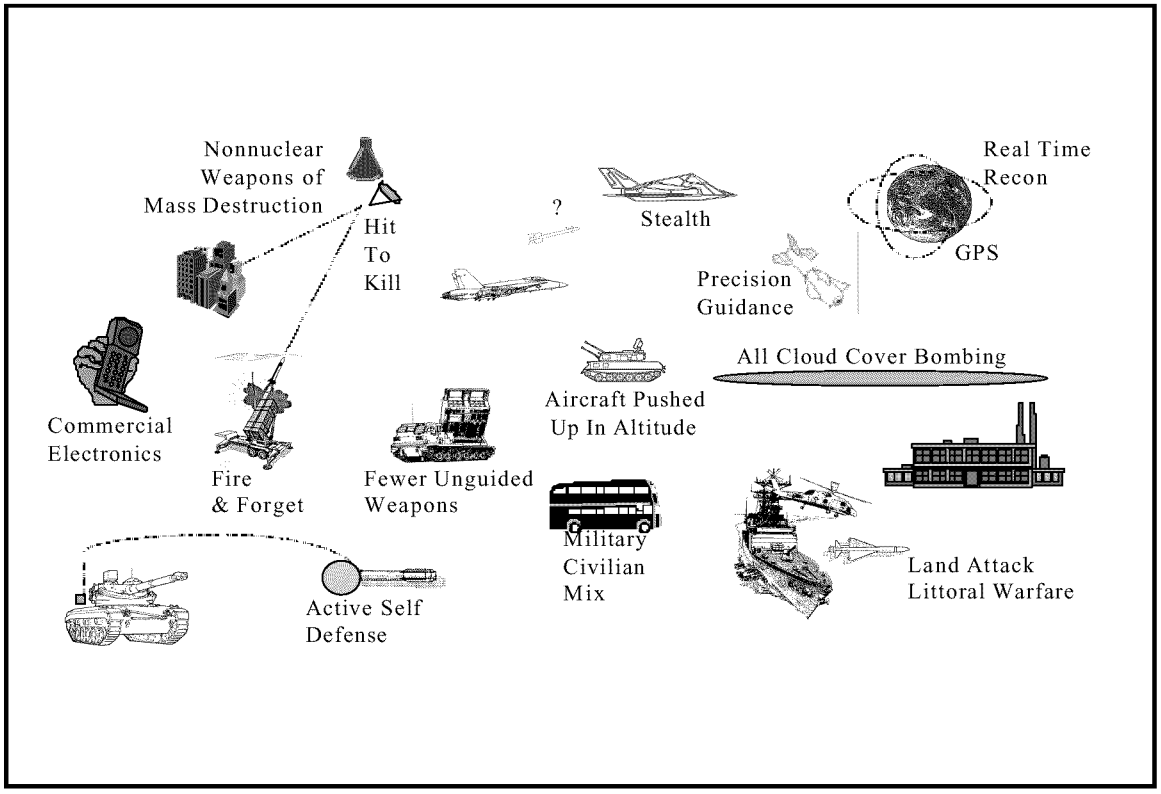


Figure 2. Changing Seeker Requirements

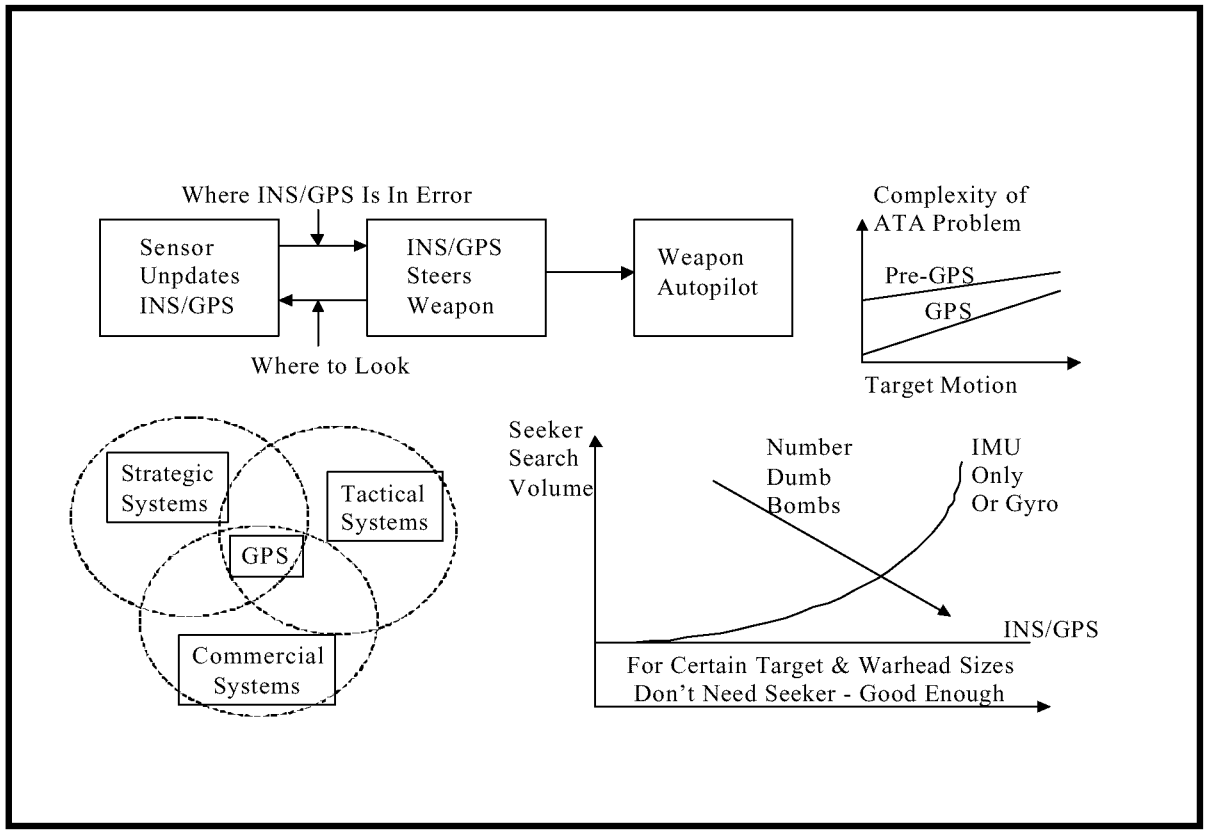


Figure 3. GPS Impact on Seeker Operation

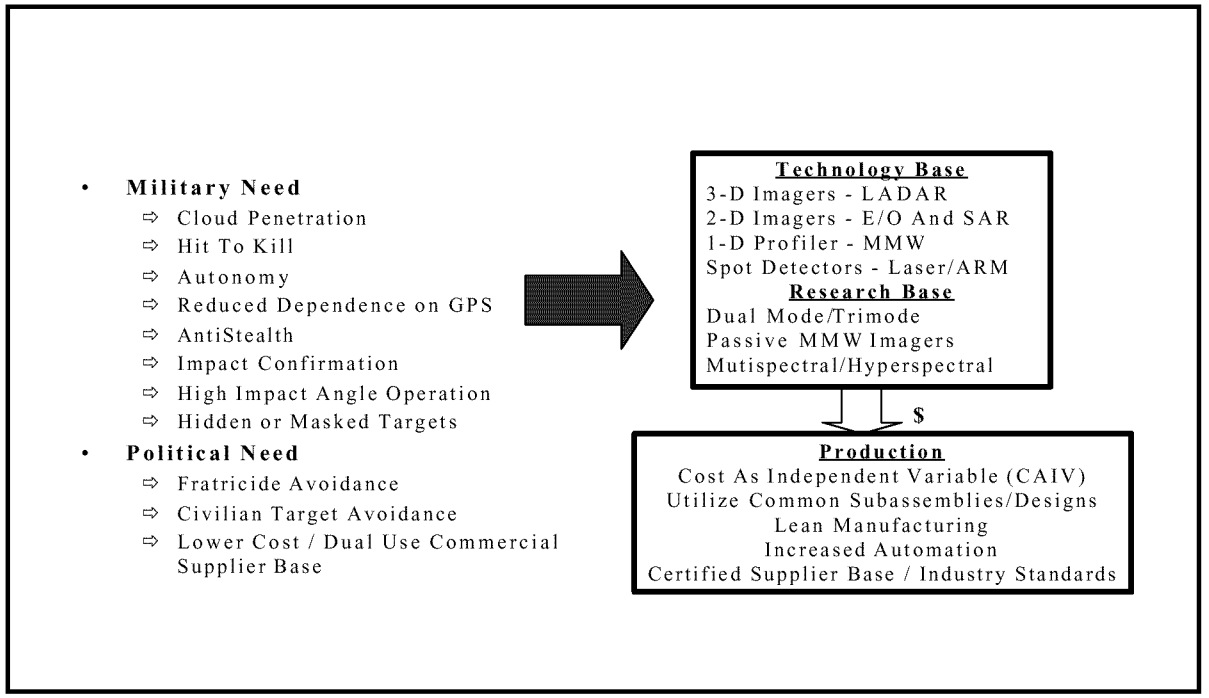


Figure 4. Future Investments

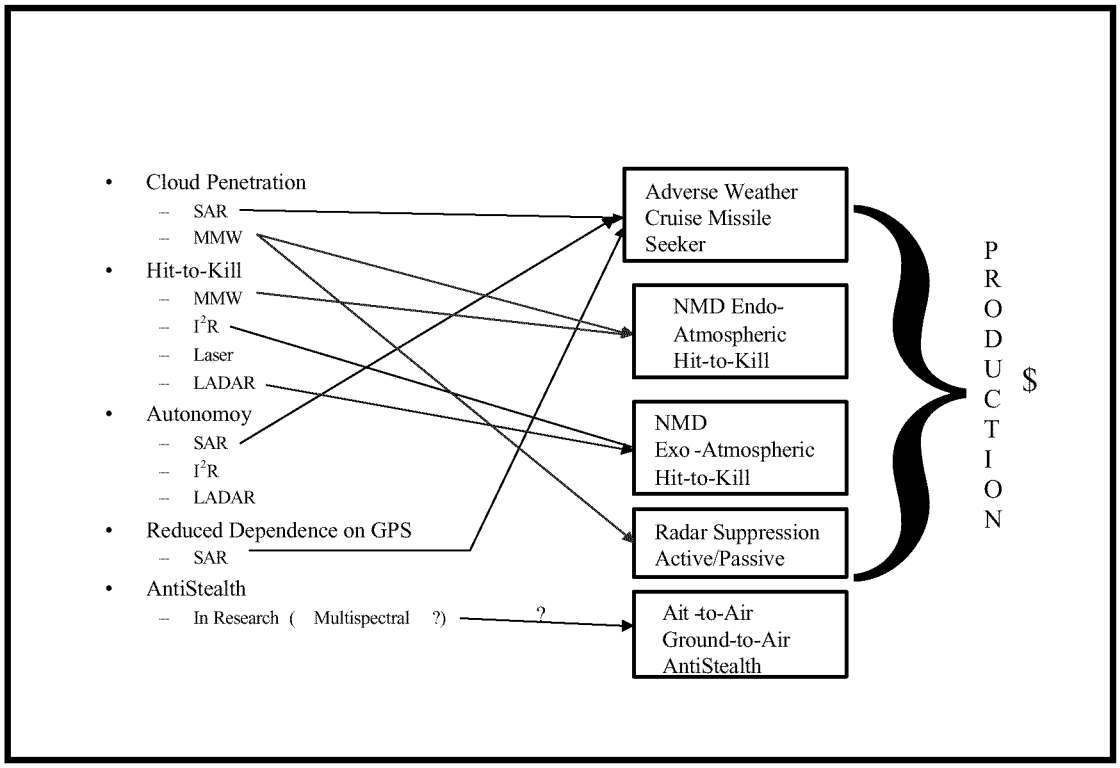


Figure 5. Seeker Versus Mission Area

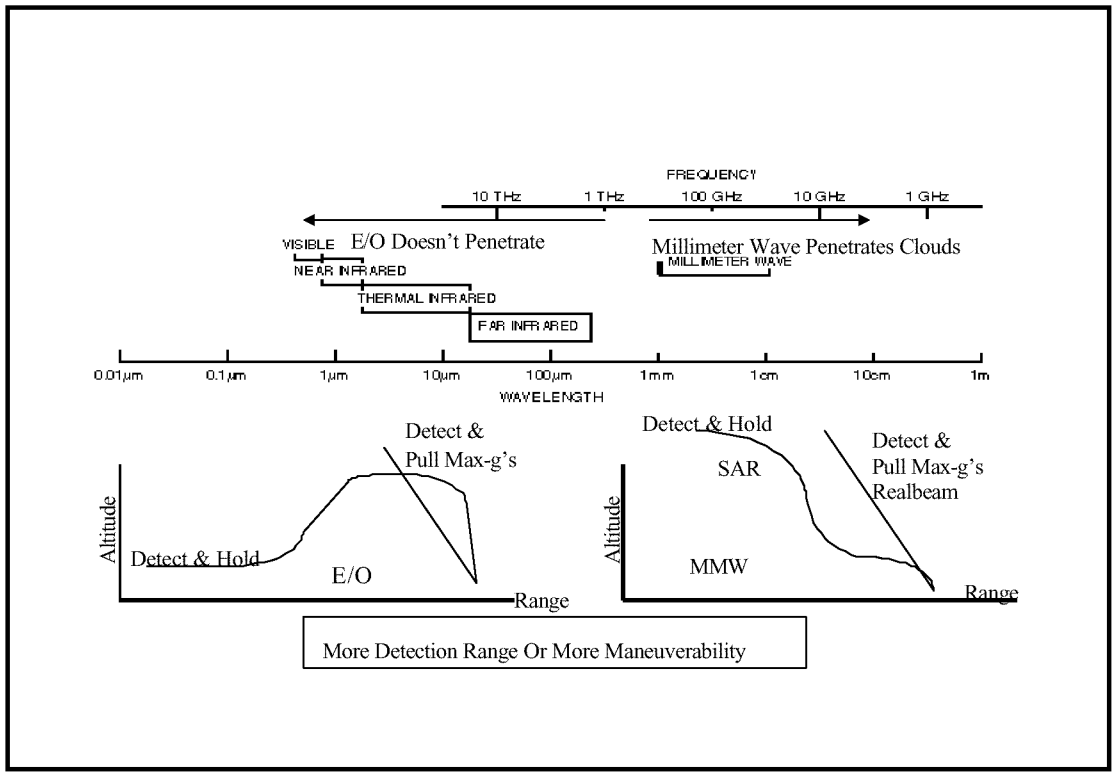


Figure 6. Cloud Penetration Problem

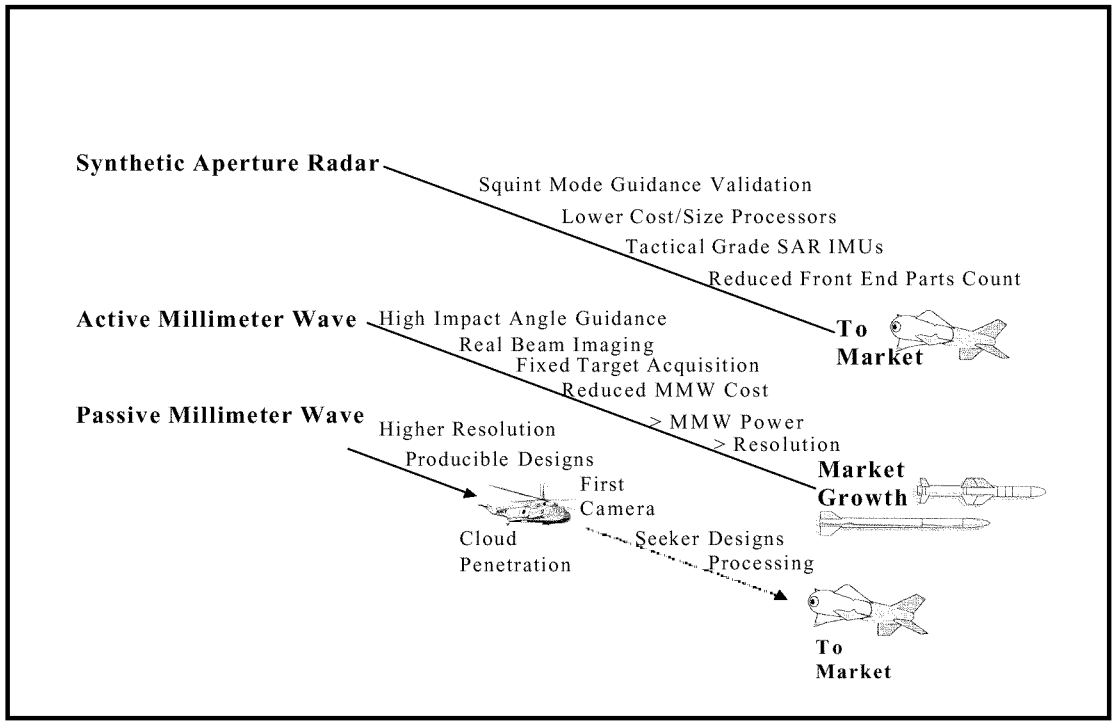


Figure 7. Radar Seeker Developments

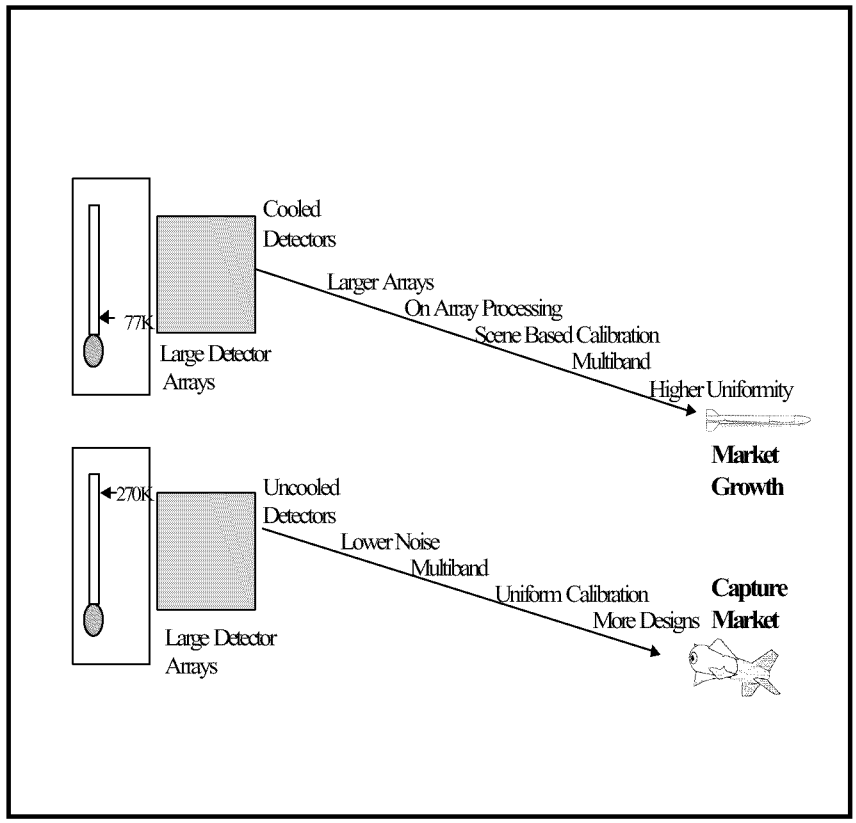


Figure 8. Trends in Infrared Seekers

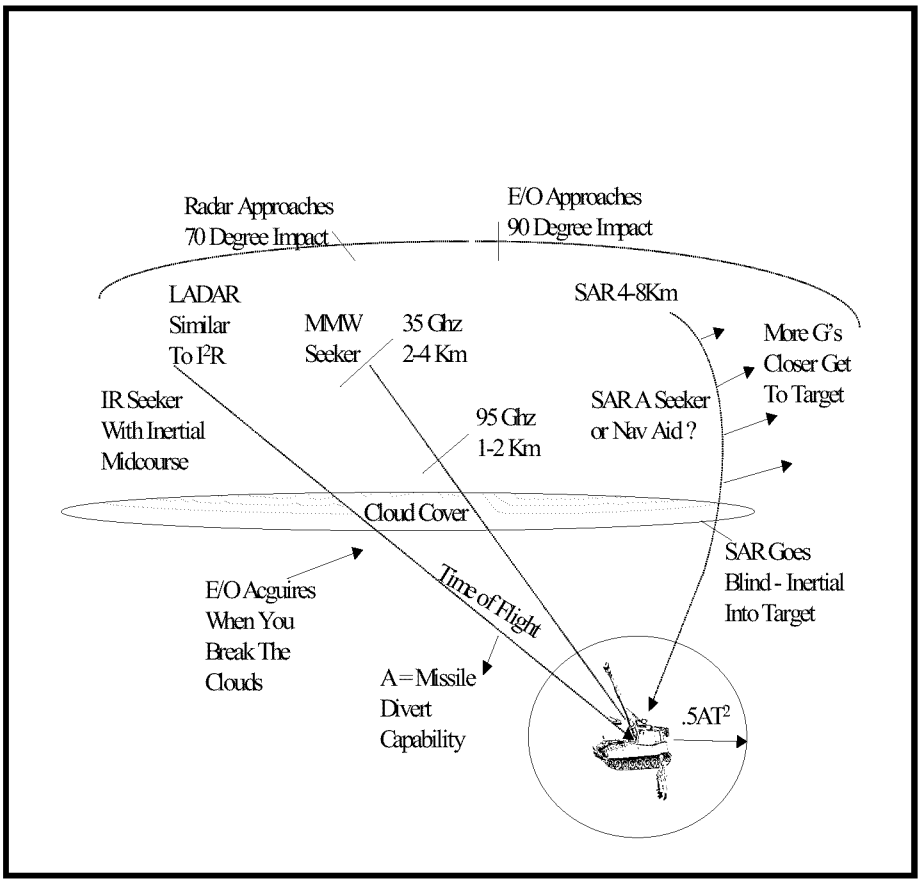


Figure 9. Airframe Seeker Trades

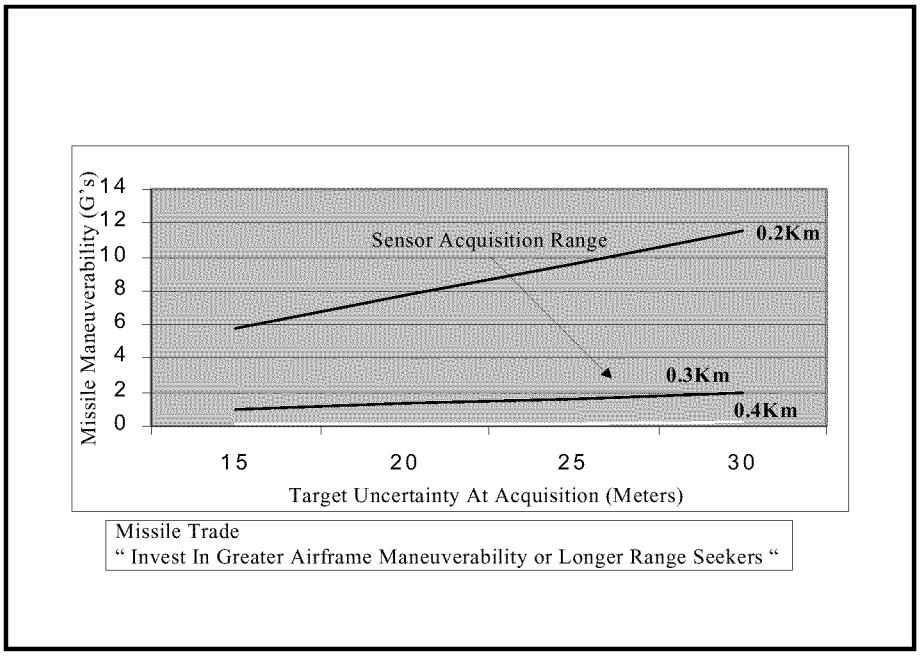
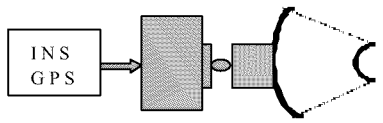


Figure 10. Required Missile Maneuverability



Generic
SAR Seeker

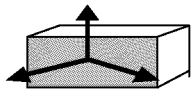
Long Range Acquisition
Time To Find Right Target/Aimpoint
High Resolution At Long Range
Consistent Imagery For ATR
All Weather (Band Dependent)
Above 16Ghz Range Degrades Some
Good Jam Resistance

Several Buts

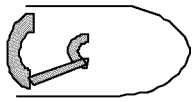
- Is It A seeker or A Navigation Aid - Will Squint Mode Guidance Yield Acceptable CEP ?
- Can It Be Packaged In A Tactical Missile Without Lose of Weapon Range or Aircraft Loadout ?
- Will The Promised Performance Be Achieved With Tactical Grade IMU ?
- Is The Technology Base Mature Enough For Transition Into Production ?
- Is There An Adequate Supplier Base For Critical Subassemblies ?
- Can It Be Made Affordable ?

First Production SAR Seeker - 2005, 2010, 2015 ?
High Enough National Priority ?

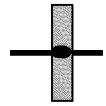
Figure 11. SAR Is Leading Adverse Weather Contender



Motion Measurement
Over Short Time Period
Accelerometer Noise
Accelerometer Transfer Function
Sensor Scale Factor Accuracy
Adequate Data Rate
Vibration
Etc.

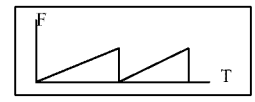


Antenna
Radome
Phase Ripple
Amplitude Ripple

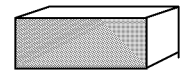


Gimbal
Structural Rigidity
Pickoff Accuracy
Pickoff Noise
Gimbal Orthogonality

SAR Requirements
↓
Flowdown To
Suppliers
↑
Program Demands



Waveform Generator
Linearity
Phase Noise
Amplitude Ripple



Processor
Approximations
Phase Error Corrections
Spatially Variant Corrections

Figure 12. SAR Subsystems

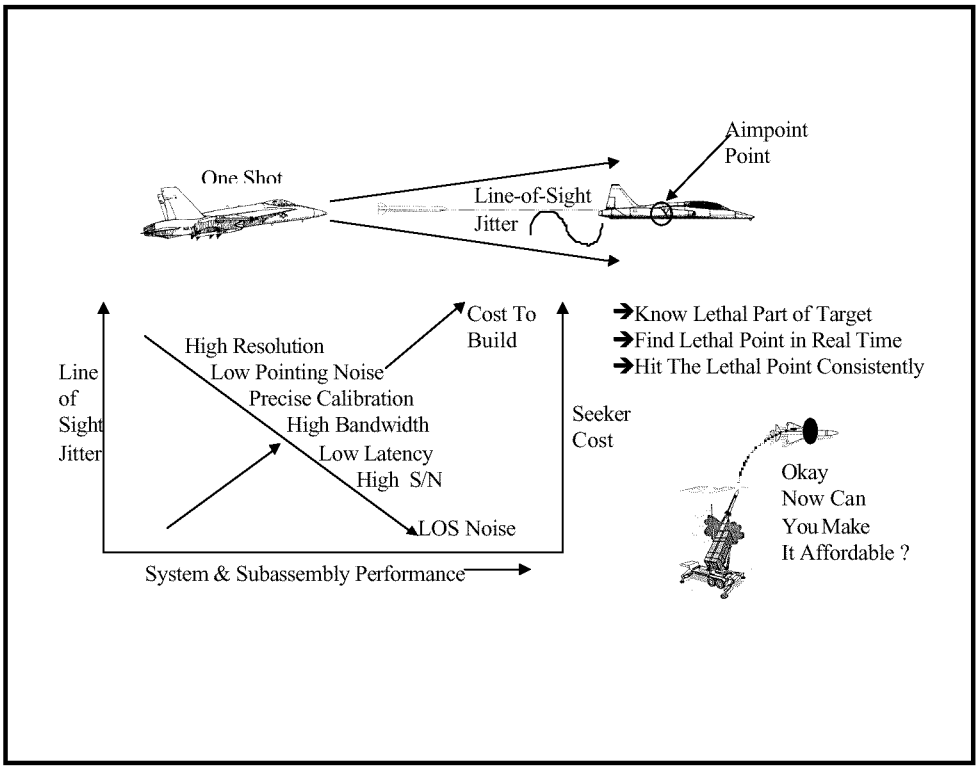


Figure 13. Hit To Kill Technology

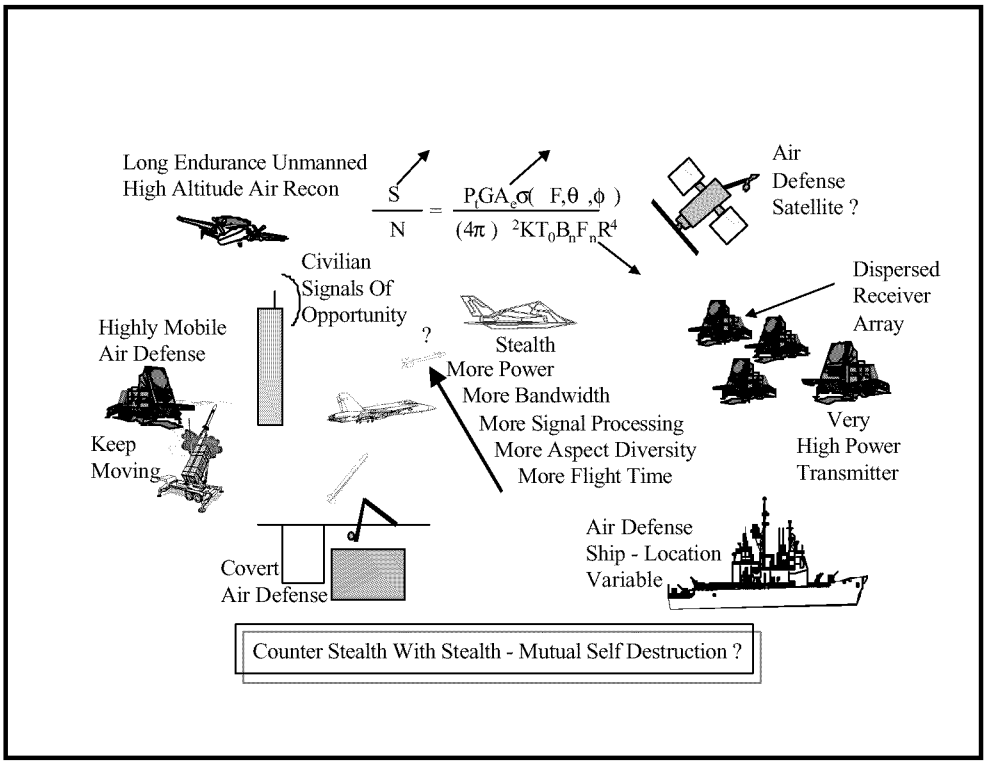


Figure 14. Defeating Stealth